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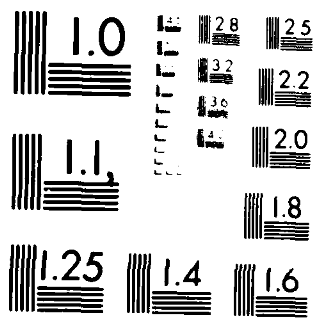

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THE STUDY OF THIN FILMS ON SEMI-INSULATING GALLIUM ARSENIDE BY ELLIPSOMETRY

Neil T. McDevitt
William L. Baun

Mechanics and Surface Interactions Branch
Nonmetallic Materials Division

June 1983

Final Report for Period January 1982 to December 1982

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MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AERONAUTICAL SYSTEMS DIVISION
WRIGHT-PATTERSON AFB, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A computer-grid procedure is discussed where delta and psi values obtained from a thin filmed surface are used to estimate the optical constants of the film-free surface. Thin films can be measured with reasonable accuracy on gallium arsenide; however, the optical constants of these films cannot be obtained.

FOREWORD

This technical report was prepared by N. T. McDevitt and W. L. Baun of the Mechanics and Surface Interactions Branch, Nonmetallic Materials Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories. The work was initiated under Project 2303, "Surface Phenomena" and WUD #50, "Surface and Interface Properties," monitored by Dr. T. W. Haas.

This report covers work performed in-house during the period January 1982 to December 1982.

The authors are grateful to Mr. Gary Griffin for his technical assistance with the computer program.

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SECTION I

INTRODUCTION

Optical methods have for a long time been extensively employed in surface studies and one of the more sensitive techniques used in this field is ellipsometry. Ellipsometry is virtually the only method for the direct determination of the optical constants of a large number of materials, and for the detection and quantitative thickness measurement of films deposited on these materials. The mathematical equations used in ellipsometry were formulated at the end of the last century; however, due to the cumbersome trigonometric equations involved in the analyses of these data, the technique, through the use of computers, has only been utilized in the last decade. This particular study was mainly accomplished through the use of McCrackin's (Reference 1) computer program for ellipsometry.

In principle, ellipsometry involves directing a monochromatic beam of linearly polarized light, at oblique incidence, onto a clean, flat reflecting surface and analyzing the state of polarization of the reflected beam. We can be a little more specific by referring to Figure 1. The plane polarized light has been rotated into s and p components, where the s component vibrates perpendicular to the plane of incidence and the p component parallel to it. The interaction of this light beam with a surface is unique and computation of the differing phase and amplitude of the orthogonal components enables the optical constants of a material to be determined. However, the application of electromagnetic theory to the reflection of light from materials containing free electrons requires the use of a complex refractive index. The free electrons cause an absorption of the incident light and the complex portion of the refractive index is justified by the fact that the imaginary part permits an easier solution to the absorption problem. The complex refractive index $\bar{n}$ is usually written $\bar{n} = n - ik$. Both n and k are positive numbers with the negative sign an arbitrary choice for the direction of propagation of the electromagnetic wave.

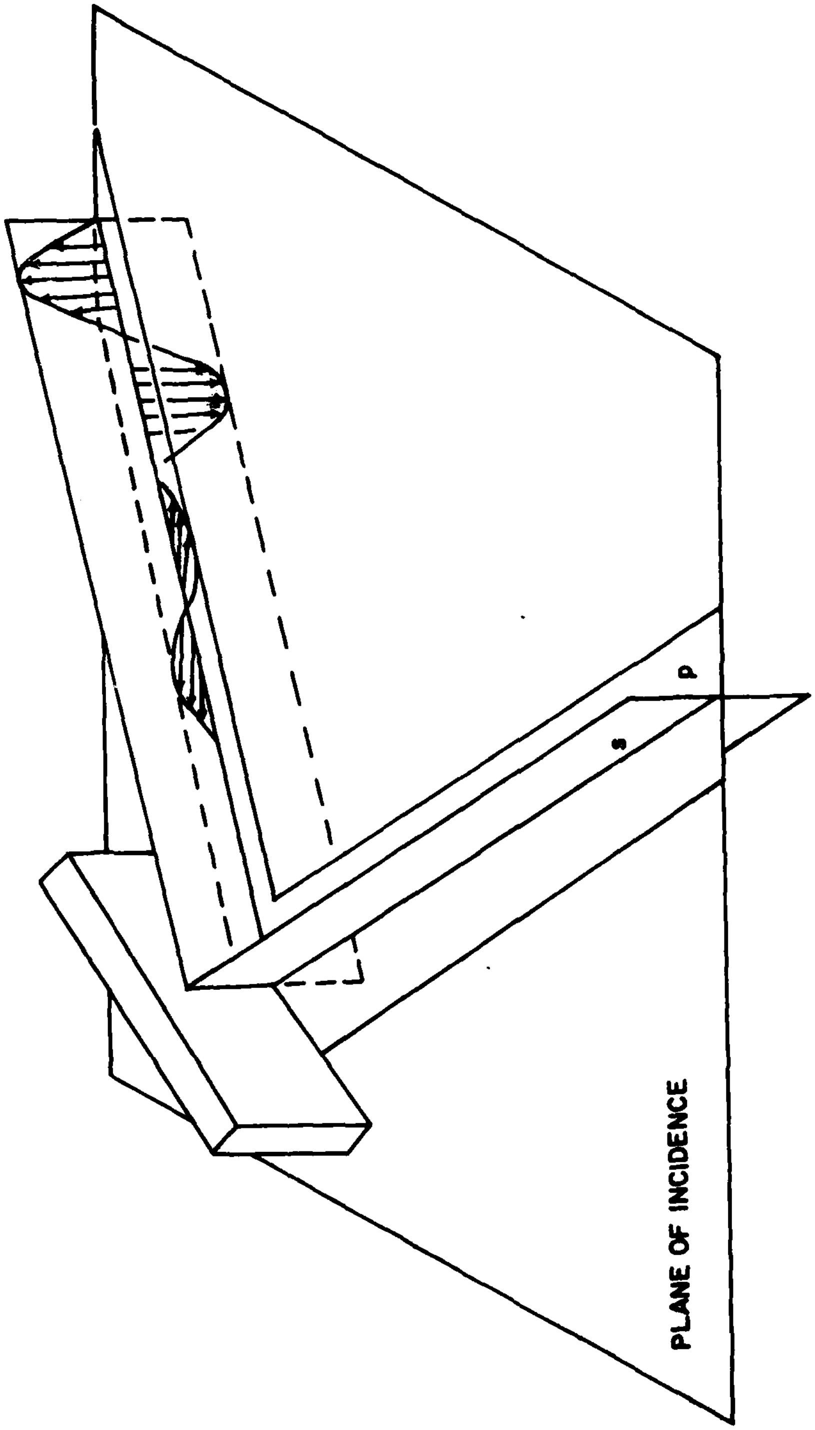

Figure 1. Reflection of Polarized Light into its Orthogonal Components

Interaction of light with this same surface when it is covered with a continuous, transparent (to the wavelength of light used) isotropic film is also unique, and often allows for the determination of the thickness of the film or its refractive index. In the case of a non-absorbing film or substate, k will be zero and the film or substrates optical constant will be designated only by n.

Our interest in ellipsometry is aimed at the study of thin films on semiconductors, in particular gallium arsenide (GaAs). Ellipsometry appears quite suitable for the study of these films for several reasons: (1) it is nondestructive by nature; (2) it can be utilized at ambient conditions; and (3) substrates can be studied under realistic processing procedures.

Thin films on semiconducting or semi-insulating GaAs are essential in device and circuit fabrication, particularly in FET (Field Effect Transistors) devices. These films help establish the appropriate properties of the GaAs surface for fabrication purposes. The determination of whether the GaAs surface is clean or contains a film, and the thickness of the film, is an important aspect of this technology. The main emphasis of this report will be on the optical characteristics of the <100> surface of the GaAs and the affects dielectrics and metal overlayers have on these properties.

SECTION II

EXPERIMENTAL

A Rudolph ellipsometer (Model 43702) was used for this study. The experimental details are described in a previous report (Reference 2). A mercury light source was used (546.1nm) and all measurements were performed at an angle of incidence of 70°. Extinction points were obtained from the polarizer and analyzer settings in Zones 1 and 3. All computations were performed on a PRIME 550+ computer. The program is capablc of performing nine different ellipsometric computations. Our main use of the program in this study was centered on the computation of delta and psi for the purpose of studying the refractive index and film thickness of semiconductor materials.

All of the semi-insulating GaAs wafers used in this study were obtained commercially. The wafers were cut from boules grown by the liquid encapsulated Czochralski process. The polished wafers are 50mm in diameter, 0.5mm thick, and are oriented on the <100> plane. No dopants were added intentionally.

SECTION III

PROCEDURE

It is necessary to have access to a computer to facilitate the computation of the ellipsometric data. Also it must be remembered that the foundation of ellipsometry is buried deeply in theoretical models. These models require the surface of the substrate to be optically smooth and film free to obtain a true refractive index. The film must be optically isotropic, homogeneous, and transparent to the wavelength of the light source. The light source has to be monochromatic. Other problems that may arise, such as precision of measurement or instrumental errors, can be found in the literature (References 3-6). Consequently, data acquisition from real surfaces still leaves the interpretation aspect of the computed data fairly subjective.

In this report we will be dealing primarily with the ellipsometric parameters delta and psi and their dependence on the values of the refractive index of the substrate (n_s), the imaginary part (k_s), and the thickness (d) of the film. All of these are referenced to an angle of incidence of 70° and 546.1nm incident light. As mentioned previously, the complex refractive index is written

$$\bar{n}_s = n_s - ik_s \tag{1}$$

where k_s is usually referred to as the extinction coefficient. However, the input into the computer program we are using will not take the value of the extinction coefficient (k_s), rather it requires the parameter called the absorption coefficient (k_s^*). k_s^* is related to k_s by the following:

$$k_s^* = \frac{k_s}{n_s} \tag{2}$$

the complex refractive index may then be written as

$$\bar{n}_s = n_s(1-ik_s^*) \tag{3}$$

Hereafter, this report will always use k_s^* when referring to the imaginary part of the refractive index.

Ellipsometry is noted for its sensitivity to changes in the surface of materials. The sensitivity of the technique can be estimated from the following equation that defines the penetration depth of the light as

$$d_p = \frac{\lambda}{4\pi n_s k_s^*} \tag{4}$$

the distance of penetration into the material which is measured in a direction normal to the surface and is dependent on the product of $n_s k_s^*$. For light of 5461Å, and several values obtained from the literature for n_s and k_s^* for gallium arsenide, the calculated penetration depth will be between 800 and 1000Å.

SECTION IV

RESULTS

1. DIELECTRIC FILMS

Ellipsometric measurements were per⁻ormed on five semi-insulating gallium arsenide wafers. These wafers were cut from the same boule. Delta and psi values were obtained from five areas on each two inch wafer. These experimental data points are plotted (solid dots) on the graph (Figure 2). The grid shown in Figure 2 was computer generated. It was formed by using a series of n and k^* values for gallium arsenide which were obtained from the literature. Each intersection on the grid represents a delta-psi value that would be obtained from a film-free surface (d=o). The spread of the data points is small and indicates the surfaces of the wafers are optically homogeneous. Because of the small spread in the data we can see from the graph that a reasonable average value for these points would be $\bar{n}_s = 3.98(1-i0.14)$. However, every gallium arsenide wafer, under ambient conditions, will have a film on the surface. The refractive index obtained from the graph will then be an apparent refractive index and not represent a film-free surface. In order to accurately obtain the thickness of a film on a surface the refractive index of the film-free surface must be known with some accuracy. This usually requires the measurement of the optical constants of a film-free surface while in an ultra-high vacuum environment. Other difficulties involved in this type of measurement are the possible damage to the surface while removing the ambient film while under vacuum, and the presence of the windows of the chamber between the light source, sample, and detector.

The following ellipsometric method is proposed as an easy and quick determination, under ambient conditions, to obtain the optical constants of a film-free surface. However, we are not proposing that this method is capable of predicting the absolute value of a film-free surface, but only a method to obtain the refractive index of a reasonably film-free surface of a particular substrate being studied.

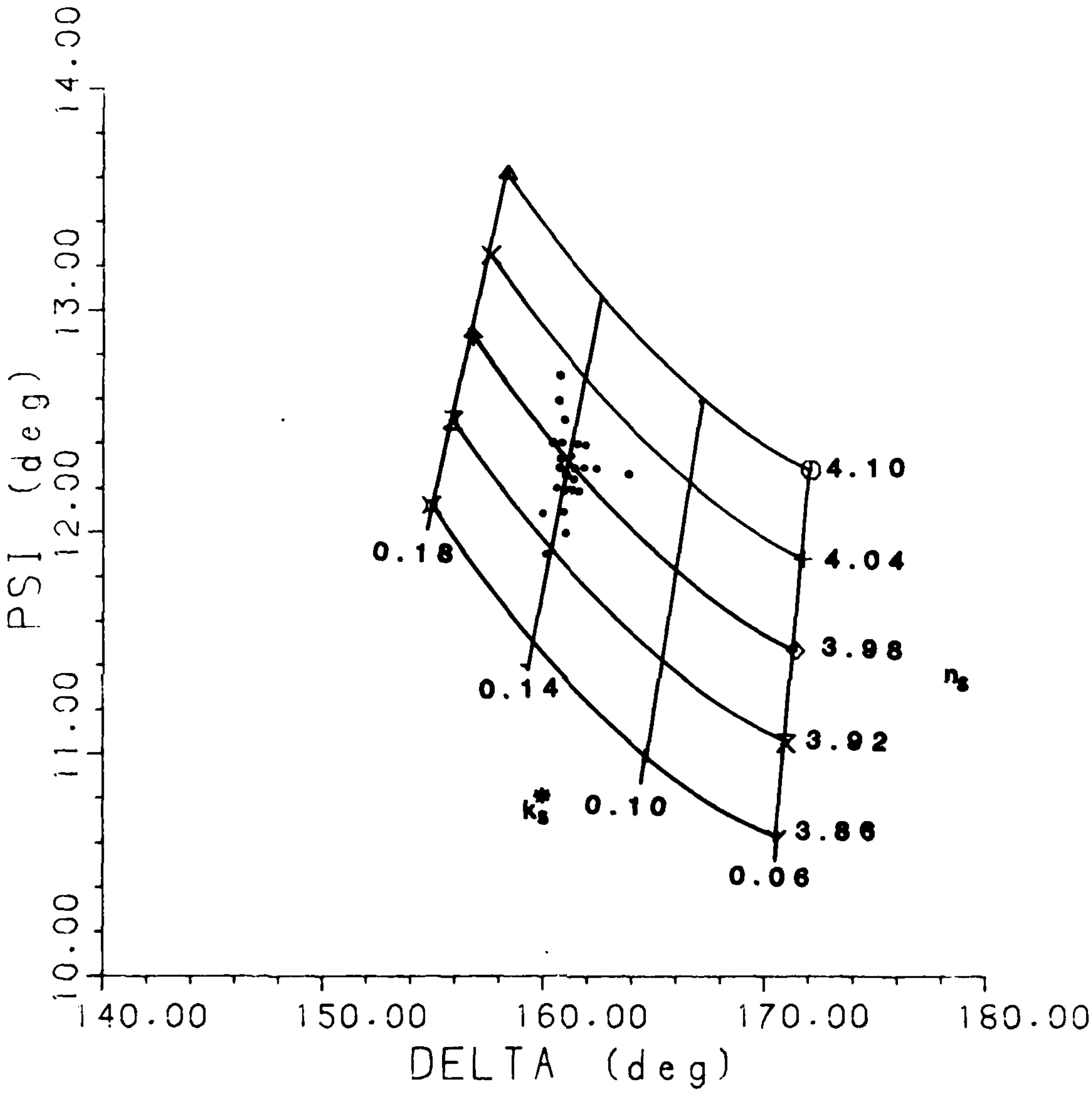

Figure 2. Computed Delta and Psi Relation for Various Complex Refractive Index Values of GaAs at Zero Film Thickness

It has been shown empirically that a nonabsorbing film on an absorbing substrate will lower the value of the real part of the refractive index while increasing the value of the imaginary part. Taking this into consideration and knowing that the data in Figure 2 represents a film covered surface, we can obtain the optical constant of a surface with a thinner film by moving to the right on the grid in Figure 2. Arbitrarily, we chose the next intersection on the grid and read $\bar{n}_s = 4.04(1-i0.1)$. We can now generate another set of curves in the following manner. Since k_s^* is very small compared to n_s, delta and psi values will be insensitive to small changes in k_s^*. Curves may then be obtained by varying the real part of the refractive index, $4.04 \pm 3\%$, and keeping the imaginary part (0.1) constant. The film growth will be 0 to 50Å with a refractive index, $n_f = 1.90$. With a film of this thickness the refractive index can vary by $\pm 5\%$ and no error will be introduced into the readings (Figure 3). From the above data a second grid can be constructed as shown in Figure 4. Plotting the experimental data on this graph (solid points) show the GaAs wafers to have a film approximately 15Å thick with the optical constants for the film-free surface being 4.04(1-i0.1). Further indications show in Figure 4 that we have a reasonable value for n_s which can be seen by the position of the open dots. These data points represent delta-psi values for several of the wafers after they have been chemically etched. The points indicate that some of the original surface film has been removed. These same wafers were subjected to a study by X-ray photoelectron spectroscopy and the corrected cross sections for the 1s line of oxygen and the Auger LMM line of gallium indicating only a small amount of oxygen is present on the surface.

By this comparison between the experimental data points and the calculated delta-psi grid diagrams, formed by varying the real part of the refractive index ($4.04 \pm 3\%$) for a 50Å film, we have demonstrated a method that should reveal the optical constants of a film-free substrate that are within the experimental error range of the unique value. The rest of the film data presented in this report will be referenced to the substrate optical constant obtained from Figure 4 where $\bar{n}_s = 4.04(1-i0.1)$. The assumption that the GaAs surface has a continuous film under ambient

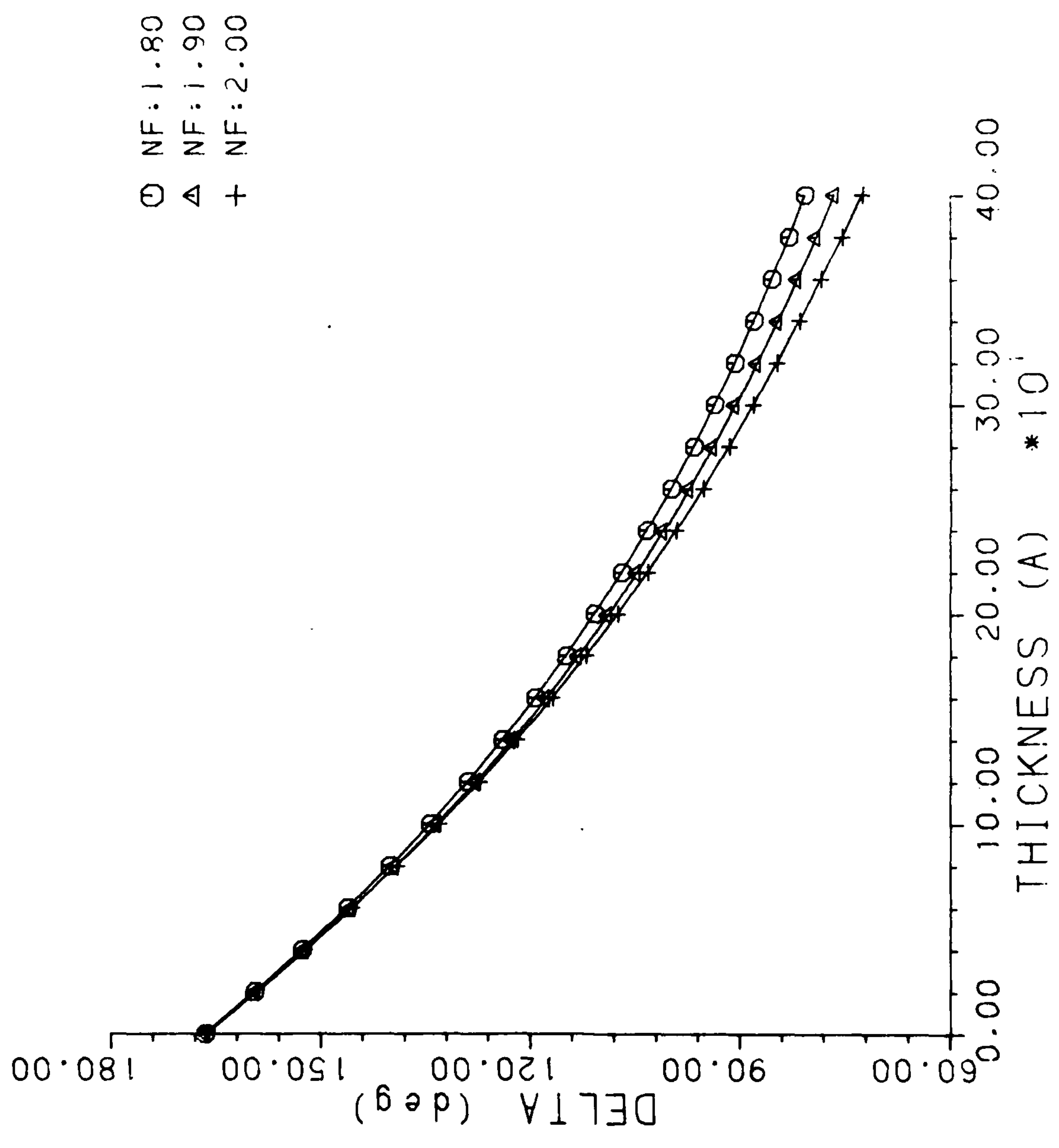

Figure 3. Computed Delta and Thickness Relation for Various Refractive Index Values of Ga_2O_3 on GaAs

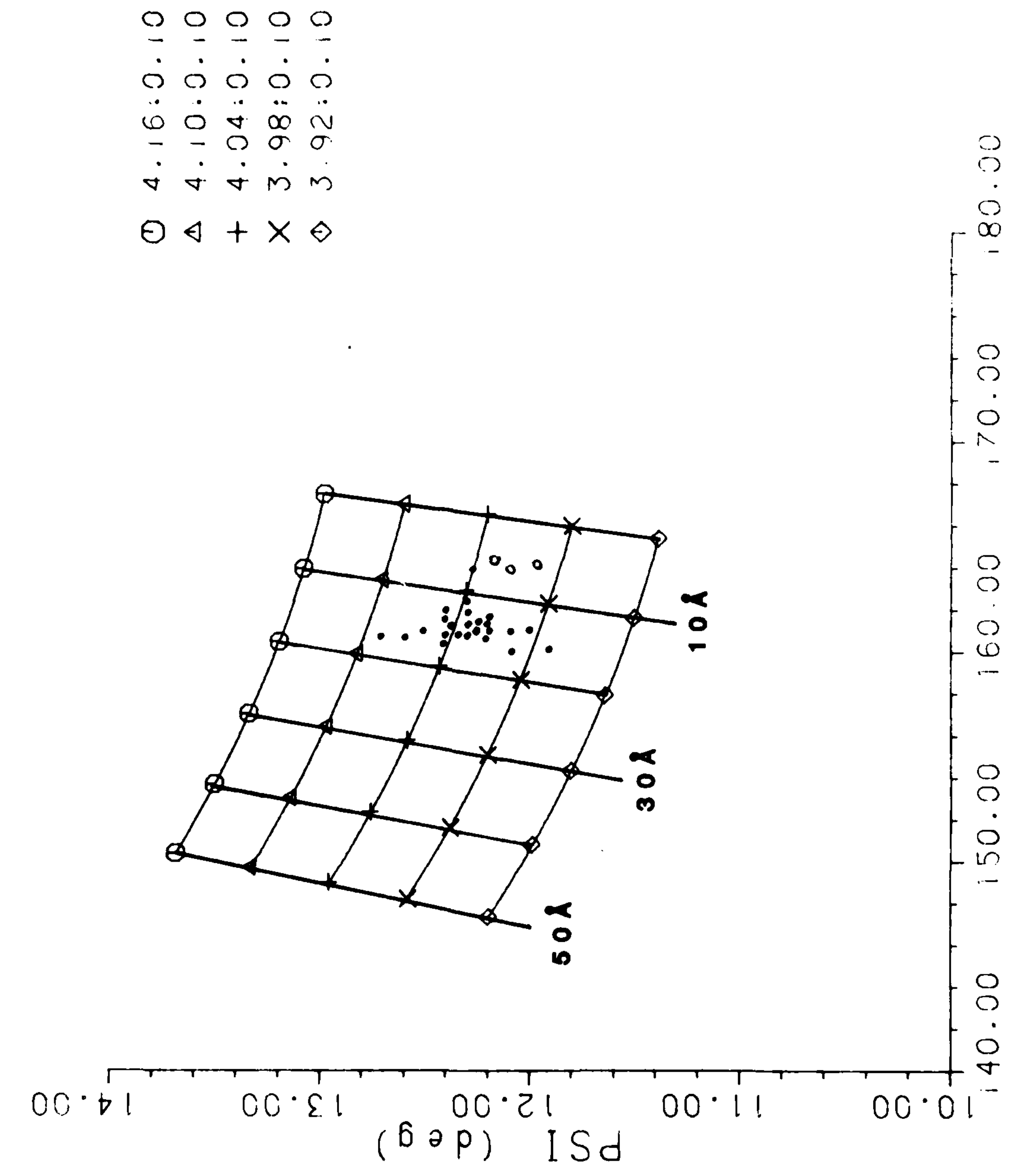

Figure 4. Computer Generated Delta and Psi Grid for GaAs for Film Thicknesses to 50Å

conditions seems valid when compared to the work (Reference 7) reported on GaAs at reduced pressures of oxygen where coverage is obtained around three monolayers. The stoichiometry of the film may be As_2O_3, Ga_2O_3 or $GaAsO_4$ but when dealing with a thin film these differences are not crucial (Figure 3) to this procedure. We also assumed that $k_f^* = 0$, however, the film may be slightly absorbing and the variations of delta and psi for thin films will not be large enough (Figure 5) to make this procedure invalid.

When a value has been established for a particular surface then delta and psi curves may be calculated for thicker films. Figure 6 shows the effect the refractive index of various films will have on the substrate being studied. A film with an index of 2.50 on this substrate will lose its sensitivity with the psi parameter and will require a fit primarily with the delta parameter. These curves were calculated using $\bar{n}_s = 4.04(1-i0.1)$, keeping the real part of the film refractive index constant and $k_f^* = 0$, while varying the thickness of the film. Figure 7 shows a similar series of curves for films that are commonly used or found on GaAs. The film was calculated for a film of 1600Å. Values for these films and several others are presented in Tables 1-5. The delta and psi values will repeat themselves after an increment of one wavelength of the light source used. This type of curve is considered closed. Comparison of delta with film thickness for a system of Ga_2O_3 on GaAs is shown in Figure 8. This figure shows the repeat pattern of a closed curve.

2. EPITAXIAL FILMS

Ternary and quaternary compounds are becoming increasingly important as CVD films on GaAs. Problems that are usually encountered in this type of film growth ɛ ·e lattice mismatch and dislocations. The use of ellipsometry in connection with vapor-phase film growth has been studied (Reference 8). Most of these films will have some free electron character, thus $k_f^* \neq 0$. When films become slightly absorbing the effect of the substrate on the reflected light becomes less pronounced as the film becomes thicker. The delta and psi curves will no longer be closed

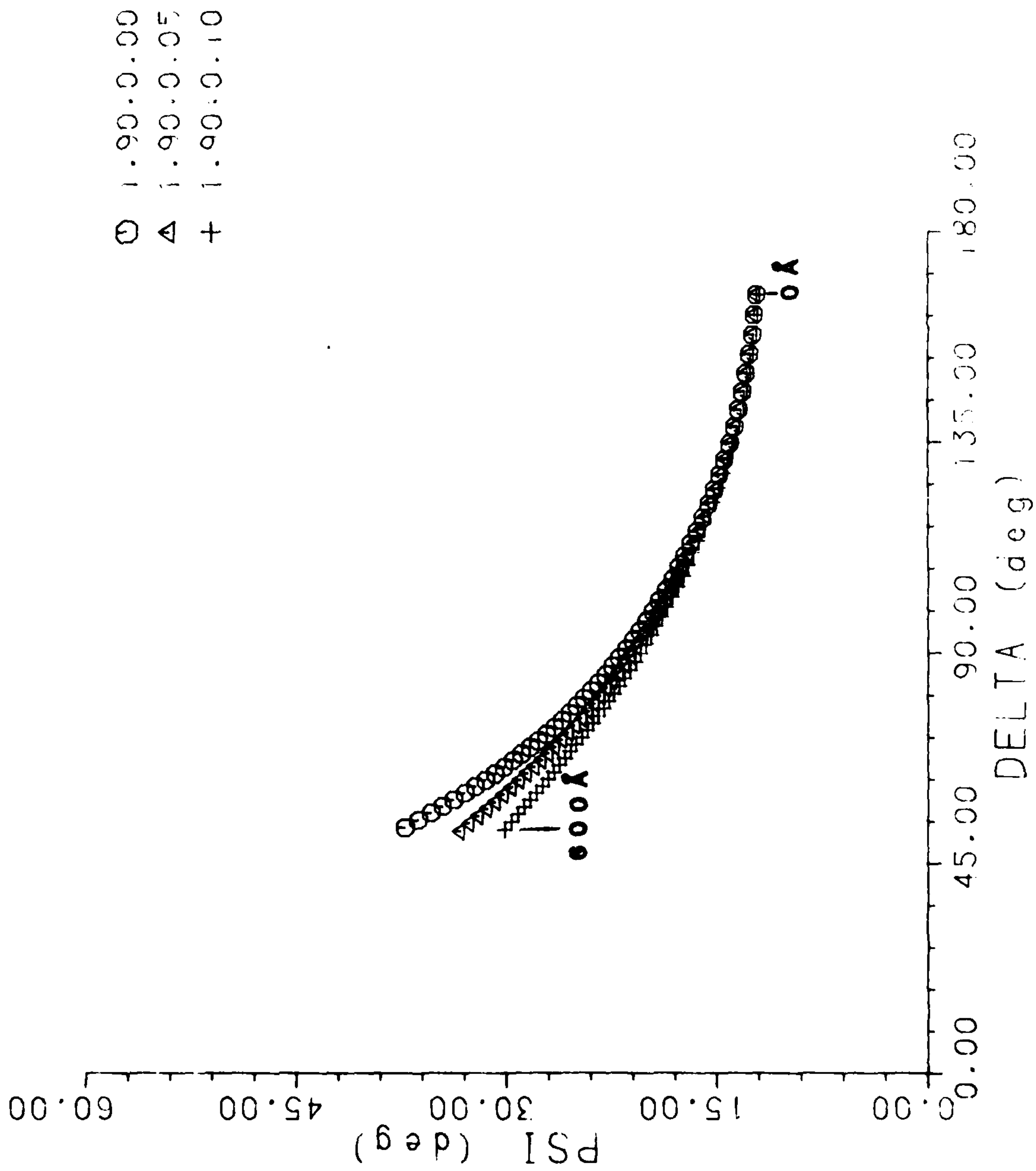

Figure 5. Computer Generated Delta and Psi Relation for a Ga_2O_3 Film Having an Imaginary Part

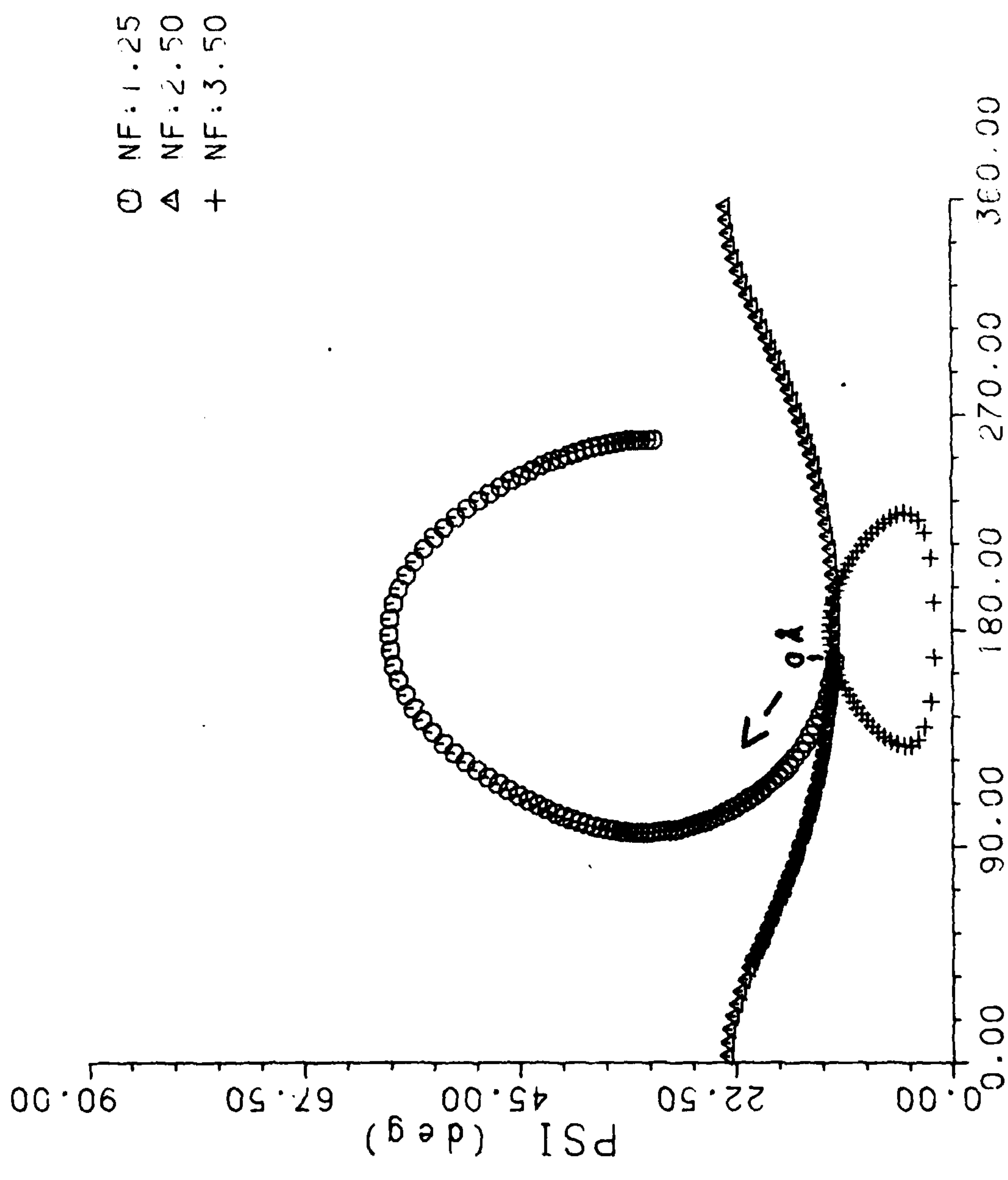

Figure 6. Relationship of *Delta* and *Psi* for Films of Varying Refractive Index on GaAs for Thicknesses up to 2400Å

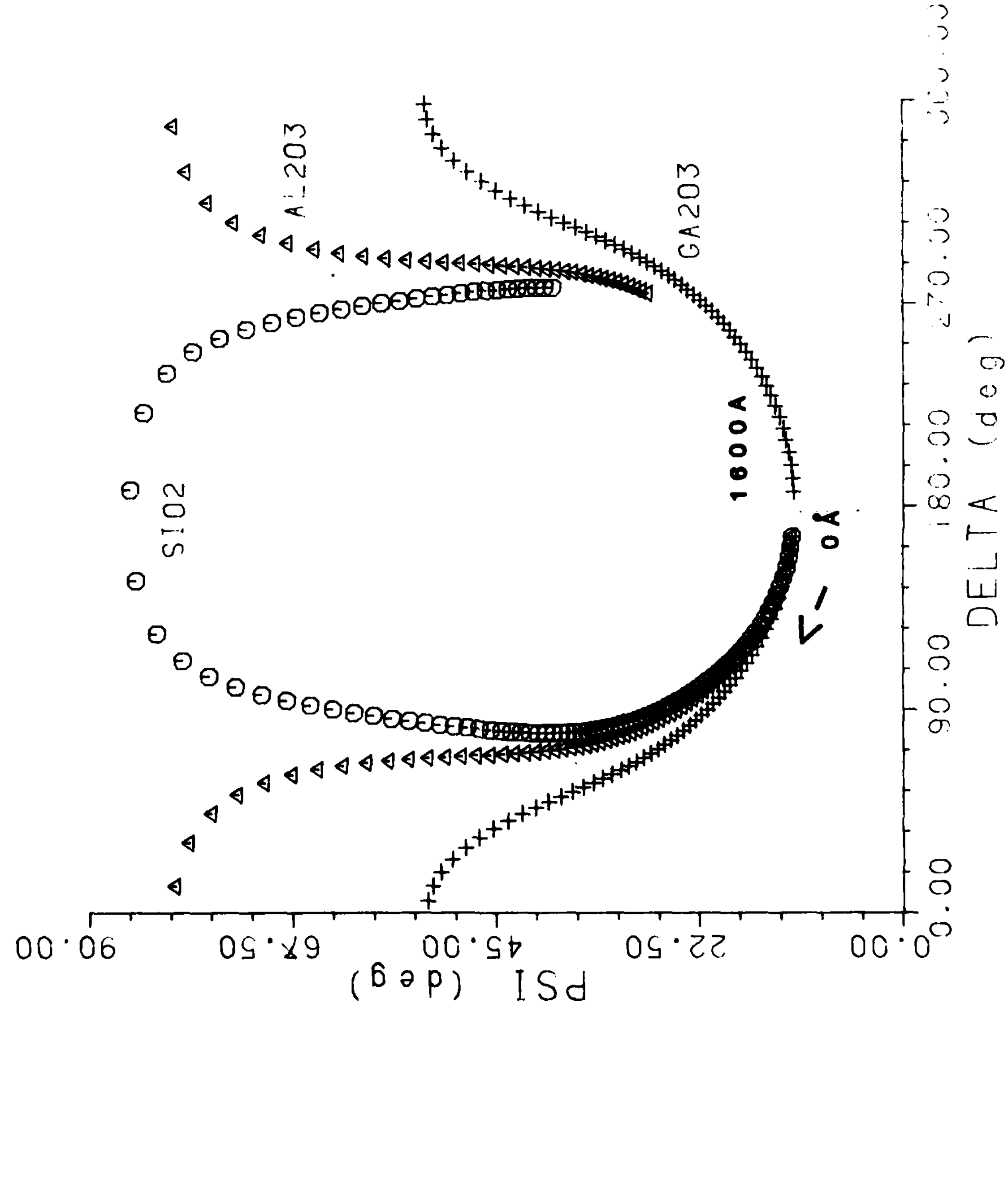

Figure 7. Relationship of Delta and Psi for Dielectric Films on GaAs

TABLE 1

CALCULATED VALUES FOR DELTA AND PSI FOR VARIOUS THICKNESSES OF Si_3N_4 ON GaAs

SI3N4//GAAS
NF 1.[illegible]
NS 4.04 0.10

THICK	DEL	PSI	RE.CF.PARALLEL		RE.CF.NORMAL	
0.0	166.534	12.202	0.18198	-14.516	0.84153	178.[illegible]
50.0	148.954	13.948	0.19255	-33.076	0.83913	177.[illegible]
100.0	133.381	14.135	0.21096	-51.465	0.83415	175.[illegible]
150.0	120.009	15.758	0.23352	-66.775	0.82759	173.716
200.0	108.592	17.538	0.25842	-80.157	0.81779	171.311
250.0	96.766	19.442	0.28397	-92.549	0.80442	169.135
300.0	90.195	21.424	0.30897	-102.826	0.78741	166.979
350.0	82.606	23.483	0.33259	-112.649	0.76512	164.744
400.0	75.776	25.649	0.35428	-121.774	0.73710	162.451
450.0	69.492	27.992	0.37366	-130.365	0.70[illegible]	160.153
500.0	63.508	30.621	0.39052	-138.512	0.65578	157.[illegible]
550.0	57.465	33.690	0.40472	-146.338	0.60728	156.197
600.0	50.767	37.369	0.41617	-153.910	0.54463	155.[illegible]
650.0	42.390	41.748	0.42485	-161.294	0.47103	156.516
700.0	30.712	46.516	0.43073	-168.547	0.40852	160.741
750.0	14.100	50.407	0.43380	-175.701	0.35079	170.179
800.0	353.672	51.331	0.43406	177.144	0.34739	-176.538
850.0	334.708	48.606	0.43156	169.970	0.38030	-164.733
900.0	320.693	43.979	0.42623	162.737	0.44170	-157.056
950.0	310.880	39.269	0.41811	155.363	0.51140	-155.496
1000.0	303.458	35.189	0.40722	147.863	0.57748	-155.605
1050.0	297.109	31.790	0.39355	140.003	0.63457	-157.026
1100.0	291.050	28.919	0.37720	131.998	0.68277	-159.052
1150.0	284.919	26.407	0.35830	123.510	0.72158	-161.310
1200.0	278.119	24.124	0.33704	114.533	0.75203	-163.616
1250.0	270.717	21.983	0.31377	104.833	0.77705	-165.884
1300.0	262.384	19.940	0.28699	94.334	0.79601	-168.090
1350.0	252.853	17.984	0.26347	82.659	0.81164	-170.195
1400.0	241.801	16.140	0.23832	69.567	0.82398	-172.234
1450.0	228.859	14.506	0.21514	54.651	0.83149	-174.256
1500.0	213.737	13.178	0.19603	37.694	0.83726	-176.133
1550.0	196.511	12.312	0.18348	18.497	0.84067	-178.024
1600.0	177.979	12.044	0.17962	-1.918	0.84187	-179.857
1650.0	159.590	12.421	0.18521	-22.180	0.84091	178.230
1700.0	142.712	13.373	0.19917	-40.945	0.83775	176.342
1750.0	127.994	14.757	0.21922	-57.563	0.83225	174.422
1800.0	115.414	16.422	0.24291	-72.132	0.82415	172.454
1850.0	104.651	18.258	0.26823	-84.926	0.81306	170.423
1900.0	95.343	20.194	0.29364	-96.340	0.79846	168.317
1950.0	87.178	22.205	0.31824	-106.692	0.77962	166.130
2000.0	79.906	24.299	0.34117	-116.226	0.75563	163.868
2050.0	73.311	26.523	0.36201	-125.126	0.72535	161.563
2100.0	67.175	28.968	0.38045	-133.532	0.68747	159.293
2150.0	61.220	31.738	0.39630	-141.551	0.64070	157.229
2200.0	55.015	35.022	0.40944	-149.272	0.58428	155.714
2250.0	47.825	38.971	0.41983	-156.764	0.51859	155.411
2300.0	38.402	43.574	0.42744	-164.091	0.44905	157.507
2350.0	24.960	48.223	0.43224	-171.308	0.38616	163.732
2400.0	6.477	51.212	0.43424	-178.465	0.34699	175.059

TABLE 2

CALCULATED VALUES FOR DELTA AND PSI FOR VARIOUS THICKNESSES OF Ga_2O_3 ON GaAs

GA2O3//GAAS
NF 1.9[illegible]
NS 4.04 0.10

THICK	DEL	PSI	REF.CF.PARALLEL		REF.CF.NORMAL	
0.0	166.534	12.202	0.18198	-14.516	0.84[illegible]	179.5[illegible]
50.0	149.007	12.955	0.15307	-33.[illegible]4	0.83[illegible]09	177.[illegible]
100.0	133.508	14.202	0.21127	-51.[illegible]	0.83[illegible]3	17[illegible].[illegible]4[illegible]
150.0	120.227	15.795	0.23406	-66.[illegible]	0.82[illegible]4	17[illegible].[illegible]
200.0	108.913	17.576	0.25921	-79.991	0.81[illegible]1	171.[illegible]
250.0	99.197	19.487	0.28564	-91.728	0.80[illegible]49	16[illegible].[illegible]7[illegible]
300.0	90.742	21.475	0.31033	-102.3[illegible]7	0.78[illegible]	16[illegible].[illegible]
350.0	83.278	23.532	0.33427	-112.579	0.76[illegible]	164.[illegible]42
400.0	76.588	25.689	0.35630	-121.1[illegible]1	0.74[illegible]72	16[illegible].[illegible]11
450.0	70.470	28.012	0.37696	-129.578	0.70[illegible]6	15[illegible].[illegible]52
500.0	64.699	30.603	0.39332	-137.6[illegible]7	0.66[illegible]9	157.[illegible]74
550.0	58.955	33.617	0.40795	-145.342	0.61[illegible]2	155.7[illegible]
600.0	52.711	37.233	0.41986	-15[illegible].789	0.55[illegible]49	154.[illegible]
650.0	45.041	41.587	0.42904	-16[illegible].0[illegible]2	0.48[illegible]46	154.[illegible]6
700.0	34.396	46.509	0.43546	-167.1[illegible]7	0.41[illegible]	15[illegible].[illegible]
750.0	18.844	50.968	0.43911	-174.2[illegible]6	0.35[illegible]49	16[illegible].[illegible]3[illegible]
800.0	358.443	52.824	0.44000	178.774	0.33[illegible]9	-17[illegible].[illegible]69
850.0	338.181	50.747	0.43814	171.766	0.35[illegible]1	-166.41[illegible]
900.0	322.861	46.170	0.43352	164.7[illegible]2	0.41[illegible]17	-158.159
950.0	312.359	41.203	0.42614	157.5[illegible]5	0.48[illegible]72	-154.[illegible]24
1000.0	304.729	36.829	0.41600	150.211	0.55[illegible]49	-154.[illegible]1[illegible]
1050.0	298.452	33.194	0.40313	142.671	0.61[illegible]19	-155.781
1100.0	292.622	30.155	0.38757	134.848	0.66711	-157.774
1150.0	285.720	27.532	0.36941	126.661	0.70[illegible]67	-160.[illegible]
1200.0	280.427	25.176	0.34882	118.068	0.74[illegible]9	-162.419
1250.0	273.508	22.986	0.32608	108.760	0.76[illegible]49	-164.748
1300.0	265.749	20.902	0.30155	98.747	0.78[illegible]71	-167.[illegible]
1350.0	256.912	18.899	0.27599	87.740	0.80[illegible]15	-169.172
1400.0	246.709	16.994	0.25124	75.441	0.81[illegible]	-171.25[illegible]
1450.0	234.757	15.242	0.22570	61.484	0.82[illegible]31	-173.274
1500.0	220.728	13.743	0.20424	45.498	0.83[illegible]08	-175.031
1550.0	204.471	12.649	0.18825	27.325	0.83[illegible]44	-177.146
1600.0	186.424	12.084	0.18017	7.398	0.84158	-179.[illegible]36
1650.0	167.813	12.172	0.18153	-13.105	0.84161	179.[illegible]82
1700.0	150.171	12.885	0.19204	-32.657	0.83[illegible]2	177.19[illegible]
1750.0	134.516	14.102	0.20982	-50.207	0.83[illegible]21	175.077
1800.0	121.086	15.667	0.23237	-65.502	0.82[illegible]0	173.321
1850.0	109.647	17.447	0.25742	-79.045	0.81[illegible]8	171.308
1900.0	99.831	19.351	0.28324	-90.546	0.80[illegible]0	169.[illegible]23
1950.0	91.297	21.334	0.30860	-101.647	0.79015	167.[illegible]56
2000.0	83.772	23.386	0.33266	-111.425	0.76[illegible]26	164.[illegible]03
2050.0	77.034	25.534	0.35484	-120.481	0.74[illegible]	162.475
2100.0	70.883	27.841	0.37476	-129.0[illegible]1	0.70[illegible]7	160.116
2150.0	65.096	30.410	0.39220	-137.077	0.66821	157.[illegible]27
2200.0	59.364	33.389	0.40701	-144.813	0.61753	155.[illegible]23
2250.0	53.179	36.957	0.41912	-152.286	0.55706	154.535
2300.0	45.651	41.259	0.42849	-159.560	0.48843	154.788
2350.0	35.278	46.162	0.43509	-166.653	0.41700	158.028
2400.0	20.114	50.713	0.43694	-173.737	0.35510	166.150

TABLE 3

CALCULATED VALUES FOR DELTA AND PSI FOR VARIOUS THICKNESSES OF As_2O_3 ON GaAs

AS2O3//GAAS
NF 1.80
NS 4.04 0.10

THICK	DEL	PSI	RF.CF.PARALLEL		RF.CF.NORMAL	
0.0	166.534	12.202	0.18198	-14.916	0.84153	17[illegible].95[illegible]
50.0	149.371	12.980	0.19352	-33.622	0.8[illegible]8	177.107
100.0	134.301	14.259	0.21237	-50.662	0.8[illegible]	175.[illegible]37
150.0	121.500	15.876	0.23597	-65.476	0.82[illegible]	173.[illegible]
200.0	110.694	17.696	0.26296	-78.355	0.82173	171.[illegible]
250.0	101.503	19.627	0.27856	-89.156	0.81[illegible]27	168.[illegible]
300.0	93.592	21.618	0.31545	-99.852	0.79[illegible]1	166.[illegible]56
350.0	86.709	23.653	0.34073	-109.098	0.77793	164.202
400.0	80.631	25.750	0.36426	-117.638	0.75[illegible]21	161.731
450.0	75.228	27.952	0.38568	-125.624	0.72[illegible]41	159.147
500.0	70.346	30.342	0.40476	-133.172	0.69[illegible]49	156.482
550.0	65.813	33.040	0.42139	-140.771	0.64788	153.816
600.0	61.372	36.218	0.43549	-147.293	0.59463	151.236
650.0	56.574	40.096	0.44705	-153.597	0.53[illegible]97	149.429
700.0	50.577	44.894	0.45605	-160.574	0.45774	148.[illegible]
750.0	41.760	50.626	0.46252	-166.951	0.37[illegible]56	151.289
800.0	27.338	56.499	0.46646	-173.218	0.30[illegible]75	159.374
850.0	5.992	60.976	0.46788	-179.545	0.26[illegible]70	175.323
900.0	349.326	58.697	0.46679	174.121	0.29[illegible]84	-166.295
950.0	322.391	53.476	0.46319	167.792	0.34[illegible]24	-154.300
1000.0	310.933	47.428	0.45725	161.388	0.41[illegible]87	-149.546
1050.0	303.791	42.089	0.44838	154.868	0.49[illegible]43	-148.923
1100.0	298.491	37.739	0.43716	148.199	0.56[illegible]21	-150.392
1150.0	293.670	34.188	0.42379	141.299	0.62[illegible]28	-152.[illegible]71
1200.0	289.320	31.229	0.40710	134.141	0.67143	-155.179
1250.0	284.504	28.656	0.38833	126.644	0.71[illegible]60	-157.859
1300.0	279.211	26.325	0.36722	119.722	0.74[illegible]19	-160.489
1350.0	273.279	24.138	0.34395	110.263	0.76753	-163.016
1400.0	266.547	22.038	0.31887	101.121	0.78775	-165.427
1450.0	258.821	19.997	0.29250	91.098	0.80378	-167.723
1500.0	249.850	18.023	0.26561	79.932	0.81632	-169.918
1550.0	239.305	16.159	0.23931	67.279	0.82594	-172.026
1600.0	226.808	14.489	0.21527	52.742	0.83395	-174.066
1650.0	212.356	13.142	0.19564	36.002	0.83754	-176.054
1700.0	195.141	12.278	0.18300	17.132	0.84[illegible]92	-178.008
1750.0	176.928	12.038	0.17951	-3.018	0.84180	-179.945
1800.0	158.955	12.464	0.18568	-22.927	0.84093	178.118
1850.0	142.622	13.477	0.20086	-41.212	0.83816	176.166
1900.0	128.540	14.920	0.22206	-57.280	0.83378	174.180
1950.0	116.641	16.639	0.24697	-71.216	0.82[illegible]41	172.143
2000.0	106.573	18.515	0.27359	-83.387	0.81[illegible]54	170.039
2050.0	97.968	20.476	0.30043	-94.182	0.80457	167.850
2100.0	90.522	22.486	0.32649	-103.918	0.78877	165.560
2150.0	84.004	24.544	0.35107	-112.839	0.76880	163.156
2200.0	78.239	26.678	0.37372	-121.126	0.74378	160.635
2250.0	73.078	28.949	0.39416	-128.911	0.71258	158.010
2300.0	68.370	31.454	0.41220	-136.300	0.67397	155.330
2350.0	63.916	34.333	0.42775	-143.371	0.62627	152.713
2400.0	59.393	37.782	0.44076	-150.193	0.56859	150.414

TABLE 4

CALCULATED VALUES FOR DELTA AND PSI FOR VARIOUS THICKNESSES OF Al_2O_3 ON GaAs

AL2O3//GAAS
NF 1.[illegible]
NS 4.04 [illegible]

THICK	DEL	PSI	RF.CF.PARALLEL		RF.CF.NORMAL	
0.0	166.534	[illegible]	0.1[illegible]	-14.[illegible]	.8[illegible]	17[illegible]
50.0	150.901	12.962	0.15[illegible]	-3[illegible]	0.84[illegible]	17[illegible]
100.0	137.225	14.191	0.21175	-47.[illegible]	[illegible]	174.[illegible]
150.0	125.671	15.741	0.23[illegible]	-61.[illegible]	[illegible]	[illegible]
200.0	116.002	17.484	0.26[illegible]	-73.477	[illegible]	[illegible]
250.0	107.876	19.227	0.28770	-83.[illegible]	.82[illegible]	[illegible]
300.0	100.987	21.212	0.31475	-93.[illegible]	[illegible]	[illegible]
350.0	95.099	23.108	0.34110	-101.330	.7[illegible]	16[illegible]
400.0	90.041	25.007	0.36624	-108.[illegible]	.7[illegible]14	[illegible]
450.0	85.693	26.917	[illegible]	-116.[illegible]	.74[illegible]	[illegible]
500.0	81.474	28.864	0.41153	-122.643	.74[illegible]	[illegible]
550.0	78.629	30.[illegible]	0.43145	-128.[illegible]	.70112	15[illegible]
600.0	76.216	33.[illegible]	0.44932	-134.[illegible]	[illegible]	14[illegible]
650.0	74.102	35.476	0.46516	-140.[illegible]	.65[illegible]70	14[illegible]
700.0	72.445	3[illegible].251	0.47898	-146.[illegible]	[illegible]	141.[illegible]
750.0	71.174	41.568	0.49081	-151.[illegible]	.55[illegible]43	1[illegible]7.440
800.0	70.152	45.[illegible]	0.50[illegible]	-15[illegible]	.4[illegible]11	[illegible]
850.0	69.080	50.661	0.50557	-161.654	.41[illegible]	1[illegible]
900.0	67.267	57.489	0.51457	-166.649	.32[illegible]	12[illegible]
950.0	62.821	65.751	0.51869	-171.[illegible]	.23[illegible]	12[illegible]
1000.0	48.741	75.[illegible]	0.5[illegible]	-176.478	.13[illegible]	134.281
1050.0	357.432	80.754	0.52136	176.641	0.06487	-17[illegible].790
1100.0	307.836	74.709	0.51992	17[illegible]	.14[illegible]15	-134.[illegible]81
1150.0	294.362	65.354	0.51663	169.641	.23[illegible]4	-12[illegible]21
1200.0	290.044	57.[illegible]80	0.51146	163.[illegible]	.33113	-126.[illegible]
1250.0	288.236	50.438	0.50449	158.[illegible]	.41[illegible]71	-129.[illegible]
1300.0	287.119	45.224	0.49541	153.7[illegible]0	0.49[illegible]	-133.419
1350.0	286.023	41.093	0.48447	148.4[illegible]7	.5[illegible]49	-137.[illegible]
1400.0	284.656	37.736	0.47153	143.[illegible]	.6[illegible]	-141.[illegible]37
1450.0	282.880	34.915	0.45659	137.41[illegible]	.65414	-14[illegible].47[illegible]
1500.0	280.623	32.452	0.43961	131.571	.6[illegible]134	-149.[illegible]
1550.0	277.941	30.[illegible]21	0.42063	125.4[illegible]6	.72210	-152.[illegible]
1600.0	274.493	28.133	0.39969	119.0[illegible]6	.7475[illegible]	-155.46[illegible]
1650.0	270.530	26.126	0.37699	112.147	.76[illegible]45	-158.[illegible]
1700.0	265.883	24.158	0.35242	104.785	.78[illegible]	-161.[illegible]
1750.0	260.452	22.209	0.32655	96.793	0.79[illegible]83	-163.[illegible]
1800.0	254.091	20.[illegible]75	0.29973	88.[illegible]3	.81175	-166.[illegible]
1850.0	246.596	18.376	0.27261	78.199	.82[illegible]62	-168.407
1900.0	237.691	16.555	0.24611	67.054	.8[illegible]	-170.[illegible]
1950.0	227.043	14.886	0.22150	54.245	0.83[illegible]7	-172.[illegible]
2000.0	214.340	13.482	0.20082	39.436	0.83763	-174.[illegible]
2050.0	199.527	12.484	0.1[illegible]603	22.552	0.84[illegible]7	-17[illegible]74
2100.0	183.142	12.03[illegible]	0.17978	4.120	.841[illegible]6	-179.[illegible]
2150.0	166.430	12.205	0.18202	-14.[illegible]33	.84153	17[illegible]37
2200.0	150.808	12.969	0.19349	-3[illegible].3[illegible]3	.84[illegible]19	176.[illegible]
2250.0	137.145	14.200	0.21192	-48.[illegible]36	.83749	174.[illegible]18
2300.0	125.604	15.752	0.23506	-61.[illegible]7	.83[illegible]37	172.71[illegible]
2350.0	115.946	17.495	0.26089	-73.5[illegible]8	.82769	170.[illegible]47
2400.0	107.829	19.339	0.28768	-83.[illegible]	.82[illegible]28	168.313

TABLE 5

CALCULATED VALUES FOR DELTA AND PSI FOR VARIOUS THICKNESSES OF SiO_2 ON GaAs

SIO2//GAAS
NF 1.4[illegible]
NS 4.[illegible]4 0.1[illegible]

THICK	DEL	PSI	RF.CF.PARALLEL		RF.CF.[illegible]L	
0.0	166.534	12.202	0.18159	-14.016	0.84153	178.950
50.0	152.321	12.901	0.19259	-30.808	0.84061	176.451
100.0	139.796	14.016	0.20939	-45.471	0.83645	174.733
150.0	129.133	15.425	0.23047	-58.293	0.83539	172.083
200.0	120.168	17.019	0.25437	-69.444	0.83190	171.388
250.0	112.625	18.716	0.27969	-79.243	0.82[illegible]43	169.132
300.0	106.241	20.458	0.30533	-87.058	0.81[illegible]47	165.901
350.0	100.904	22.211	0.33072	-95.015	0.80596	163.476
400.0	96.158	23.958	0.35533	-103.0[illegible]3	0.79[illegible]67	16[illegible].[illegible]39
450.0	92.190	25.693	0.37889	-109.642	0.78734	159.169
500.0	88.923	27.424	0.40091	-115.918	0.77[illegible]64	155.338
550.0	86.008	29.168	0.42156	-121.470	0.75518	152.423
600.0	83.715	30.952	0.44049	-127.197	0.73447	149.069
650.0	81.932	32.817	0.45782	-132.467	0.70994	145.[illegible]01
700.0	80.662	34.814	0.47349	-137.501	0.68[illegible]90	141.[illegible]17
750.0	79.919	37.014	0.48747	-142.391	0.64655	137.[illegible]89
800.0	79.730	39.513	0.49981	-147.105	0.6[illegible]6[illegible]3	133.164
850.0	80.135	42.436	0.51053	-151.608	0.55[illegible]40	128.178
900.0	81.189	45.946	0.51966	-156.161	0.50278	122.650
950.0	82.983	50.252	0.52723	-160.543	0.43647	116.474
1000.0	85.679	55.599	0.53328	-164.853	0.36515	109.466
1050.0	89.655	62.228	0.53782	-169.1[illegible]7	0.28222	101.036
1100.0	96.090	70.549	0.54088	-173.323	0.19421	90.587
1150.0	110.756	79.310	0.54248	-177.514	0.10241	71.731
1200.0	187.410	85.425	0.54262	178.354	0.04342	-9.106
1250.0	249.452	78.088	0.54130	174.116	0.11419	-75.336
1300.0	262.122	69.053	0.53851	169.906	0.20614	-92.016
1350.0	268.070	61.145	0.53425	165.660	0.29478	-102.410
1400.0	271.803	54.625	0.52849	161.362	0.37524	-110.441
1450.0	274.318	49.359	0.52121	156.995	0.44738	-117.523
1500.0	275.947	45.103	0.51238	152.541	0.51053	-123.406
1550.0	276.838	41.616	0.50196	147.980	0.56506	-128.858
1600.0	277.073	38.692	0.48992	143.293	0.61170	-133.760
1650.0	276.704	36.172	0.47625	138.454	0.65137	-138.250
1700.0	275.767	33.936	0.46090	133.437	0.68497	-142.329
1750.0	274.283	31.891	0.44389	128.210	0.71339	-146.072
1800.0	272.260	29.970	0.42521	122.735	0.73738	-149.525
1850.0	269.694	28.122	0.40492	116.966	0.75764	-152.728
1900.0	266.562	26.312	0.38309	110.844	0.77471	-155.718
1950.0	262.821	24.515	0.35986	104.295	0.78907	-158.526
2000.0	258.401	22.720	0.33544	97.224	0.80112	-161.178
2050.0	253.202	20.926	0.31017	89.503	0.81117	-163.699
2100.0	247.075	19.145	0.28449	80.965	0.81947	-166.111
2150.0	239.821	17.409	0.25907	71.390	0.82623	-168.431
2200.0	231.188	15.768	0.23483	60.510	0.83163	-170.678
2250.0	220.895	14.299	0.21302	48.029	0.83578	-172.867
2300.0	208.745	13.105	0.19526	33.733	0.83878	-175.012
2350.0	194.827	12.307	0.18341	17.700	0.84070	-177.126
2400.0	179.758	12.012	0.17907	0.534	0.84159	-179.224

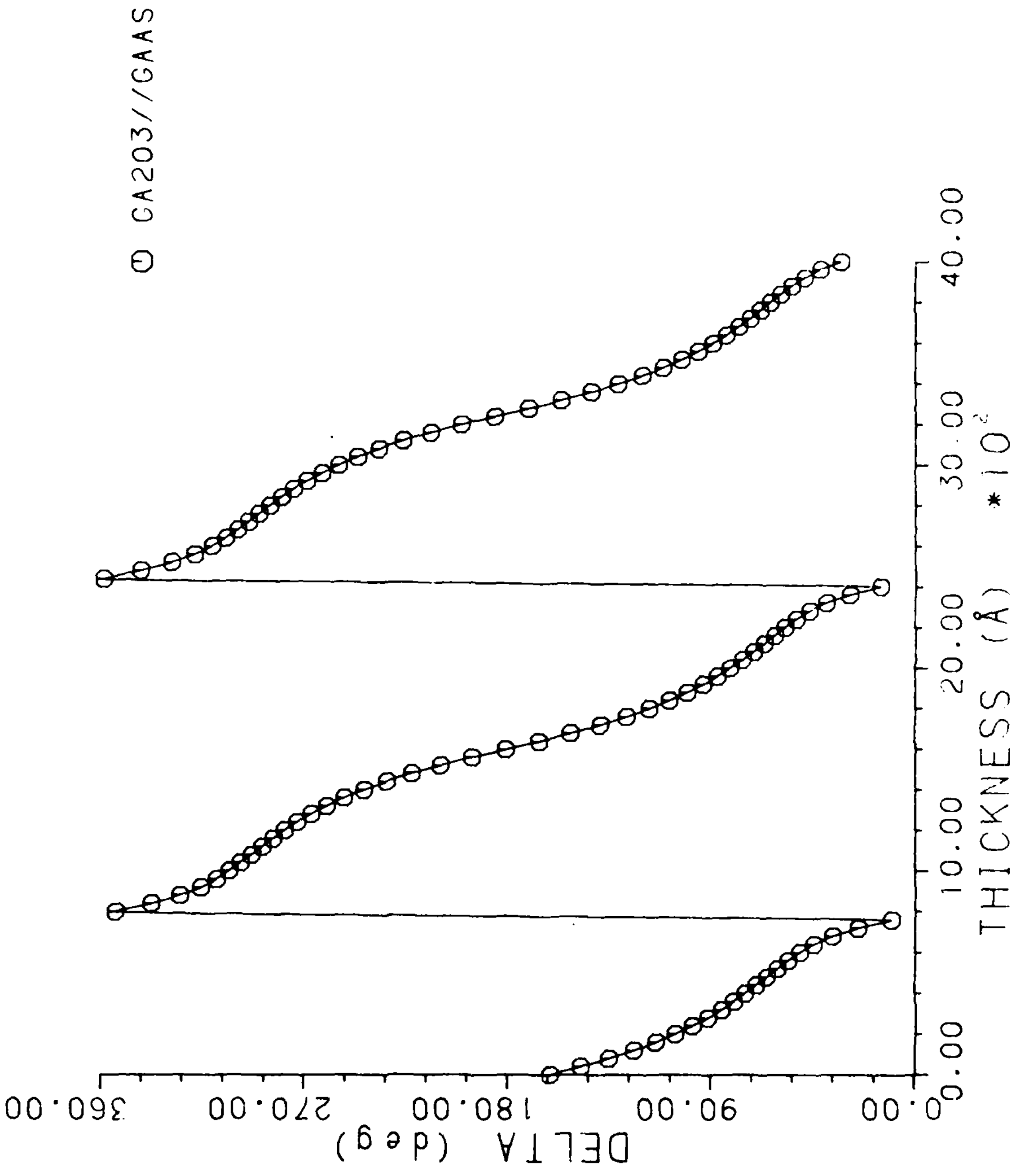

Figure 8. Relationship of Delta and Thickness for a Closed Curve of Ga_2O_3 on GaAs

for this type of film. The delta and psi values will approach the values representative of the bulk film with increasing film thickness. This type of curve, shown in Figure 9, is calculated for GaAlAs/GaAs where $\bar{n}_f = 4.2(1-i0.067)$. A comparison of delta and thickness values for this system (Figure 10) shows a dampened curve as the substrate becomes increasingly obscured by the film. The magnitude of the absorption character of the film would determine the usefulness of ellipsometry for each epitaxial film studied. For the film data shown in Figure 10 information could be reasonably obtained from a 200Å film and possibly up to 600Å. Thicker films would become increasingly difficult to interpret using null ellipsometry.

3. METAL FILMS

The use of ellipsometry in connection with programs dealing with contacts and interconnects on compound semiconductors was reviewed. A short study was performed looking at a small number of metal films on GaAs. The absorption character (k_f^*) of metallic films is usually greater than 0.25. The limitation of the sensitivity of ellipsometry will depend primarily on the value of k_f^* of each film studied. Knowing this limitation will be an important aspect of a study concerning metal films. The metal films looked at in this study were, nickel 1.4-(1-i1.8), gold 0.43(1-i5.12), and germanium 5.46(1-i0.32). The delta and psi curves (Figure 11) are characteristic of metal films and show an entirely different response when compared to dielectric and epitaxial films. These data were generated for 400Å thick films and a comparison of delta and thickness is reported in Figure 12. Sensitivity for the GaAs surface will become obscure for nickel and gold around 150Å, while germanium films may be studied to 300Å. However, the germanium film will suffer in sensitivity where the maximum occurs in the curve.

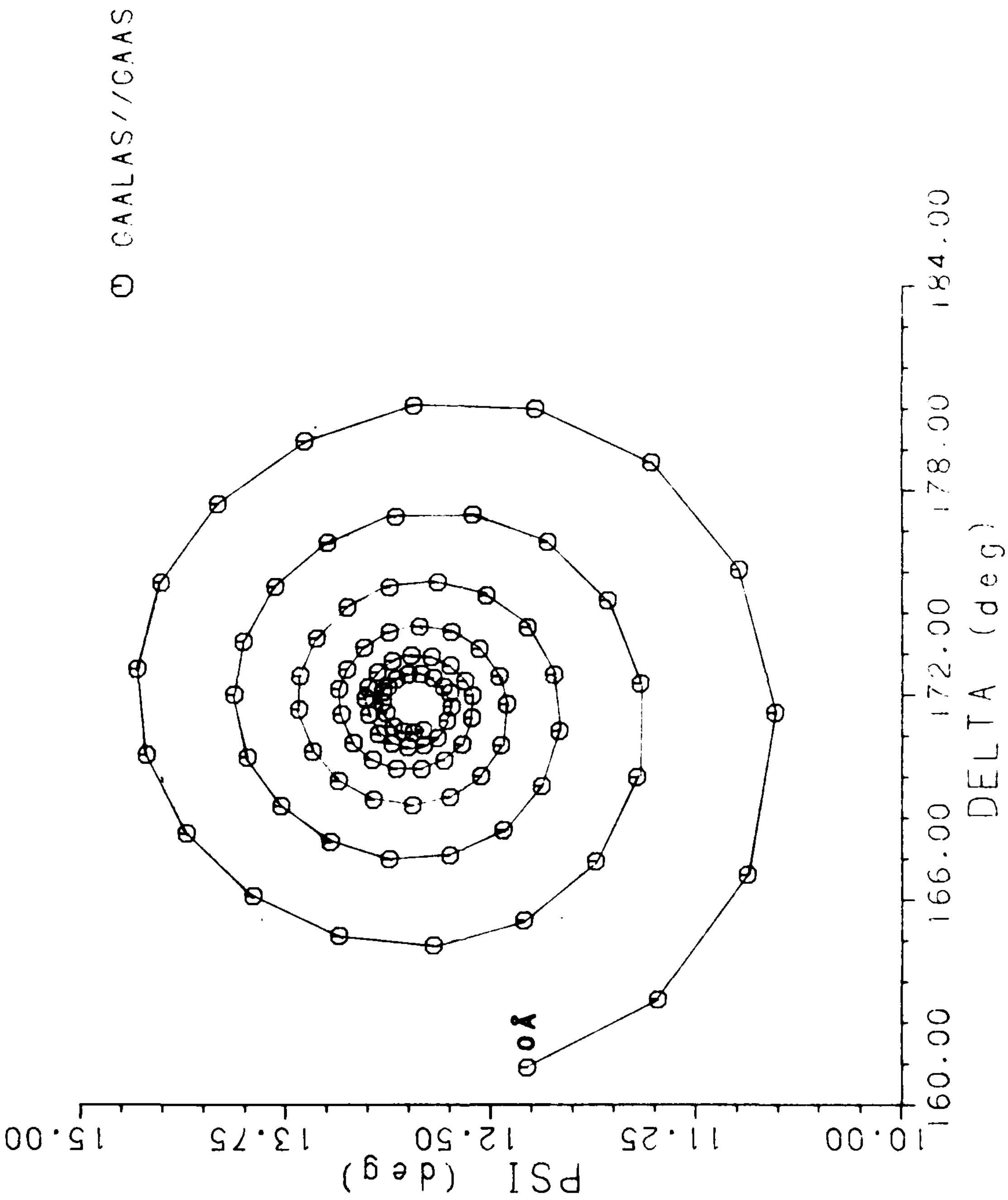

Figure 9. Computed Delta and Psi Relation for Epitaxial Film GaAlAs on GaAs for a Thickness of 2500Å

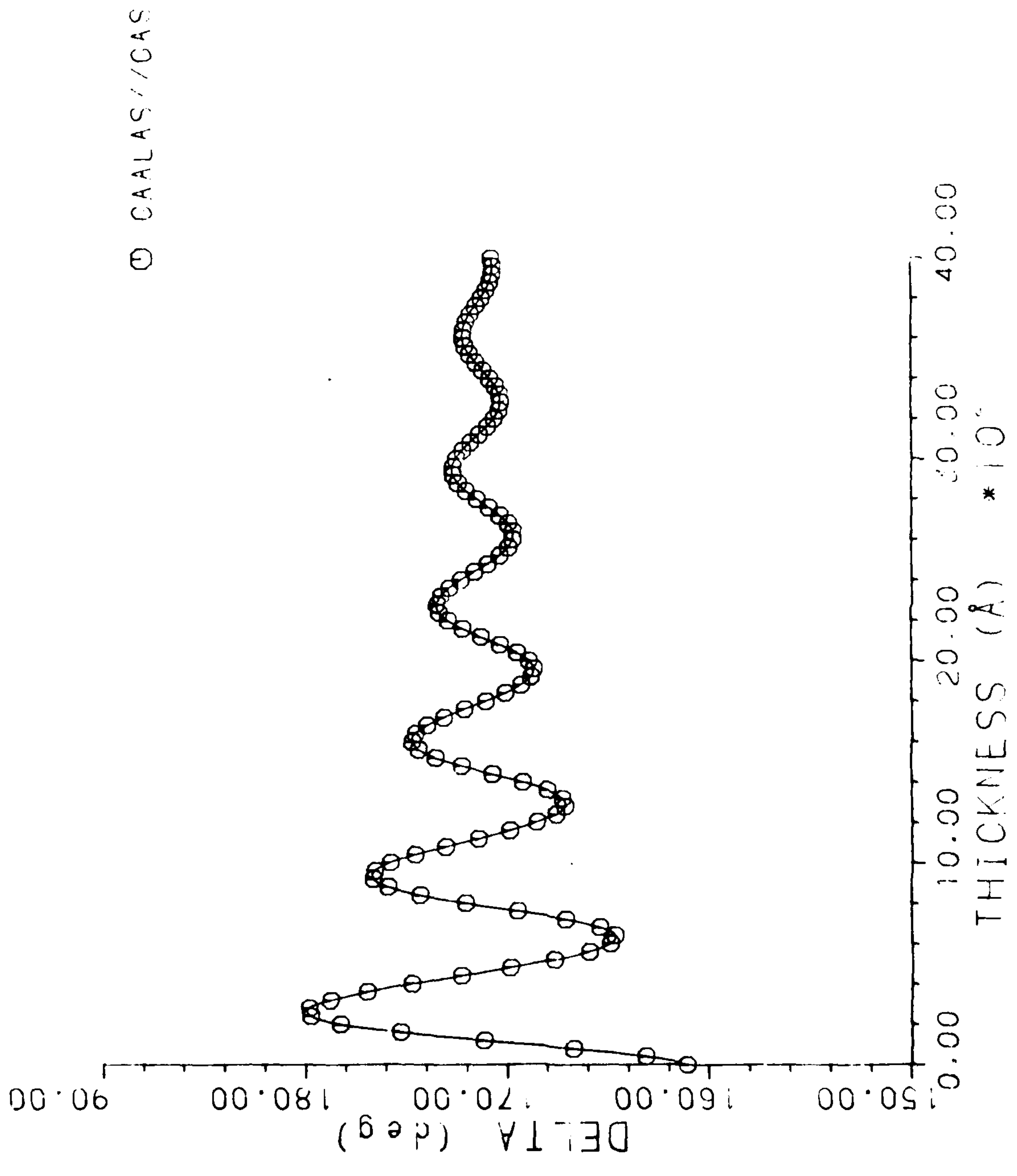

Figure 10. Relationship of Delta and Thickness Showing a Dampened Curve for GaAlAs

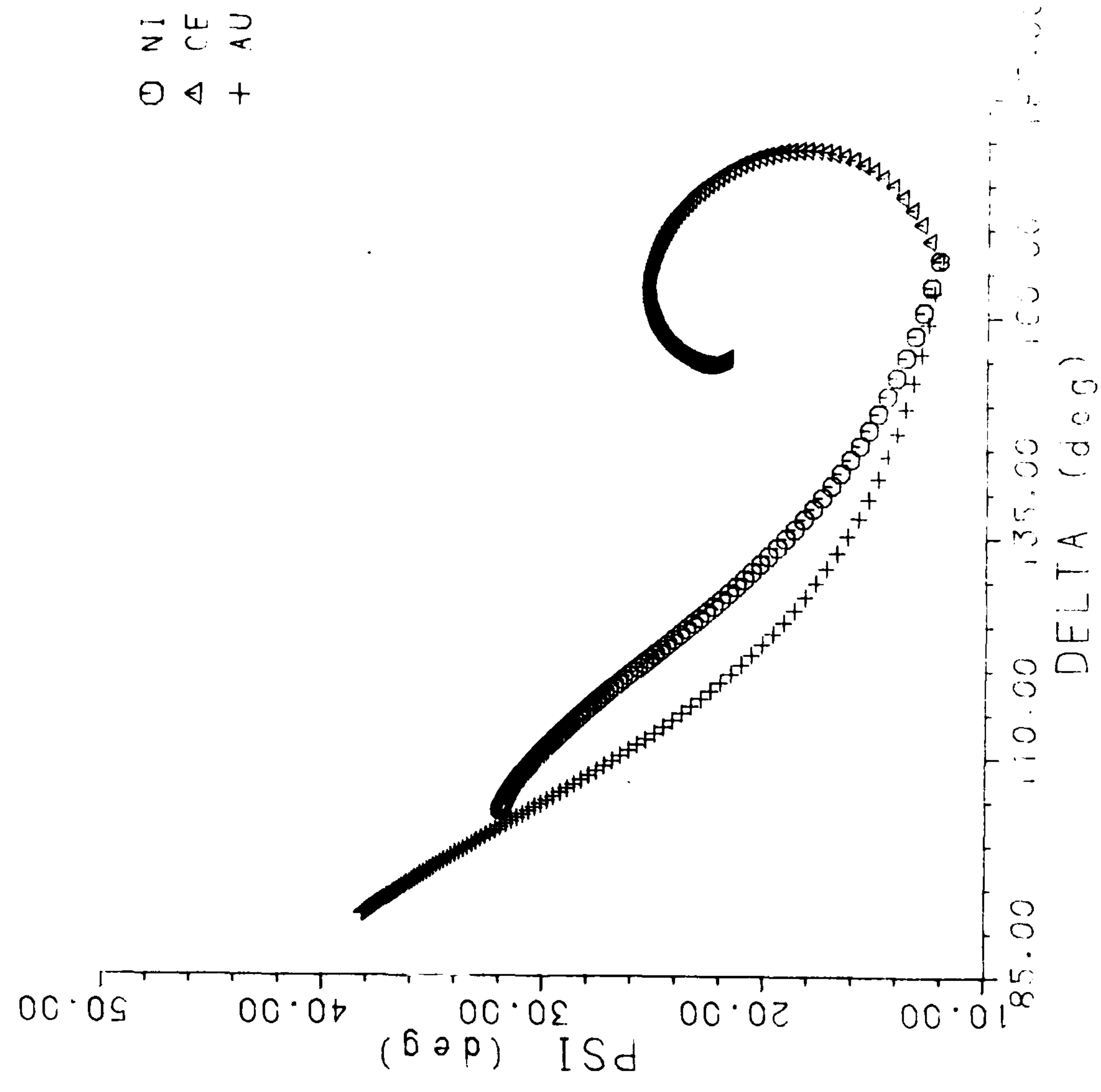

Figure 11. Relationship of Delta and Psi for Metal Films on GaAs for a Thickness of 400Å

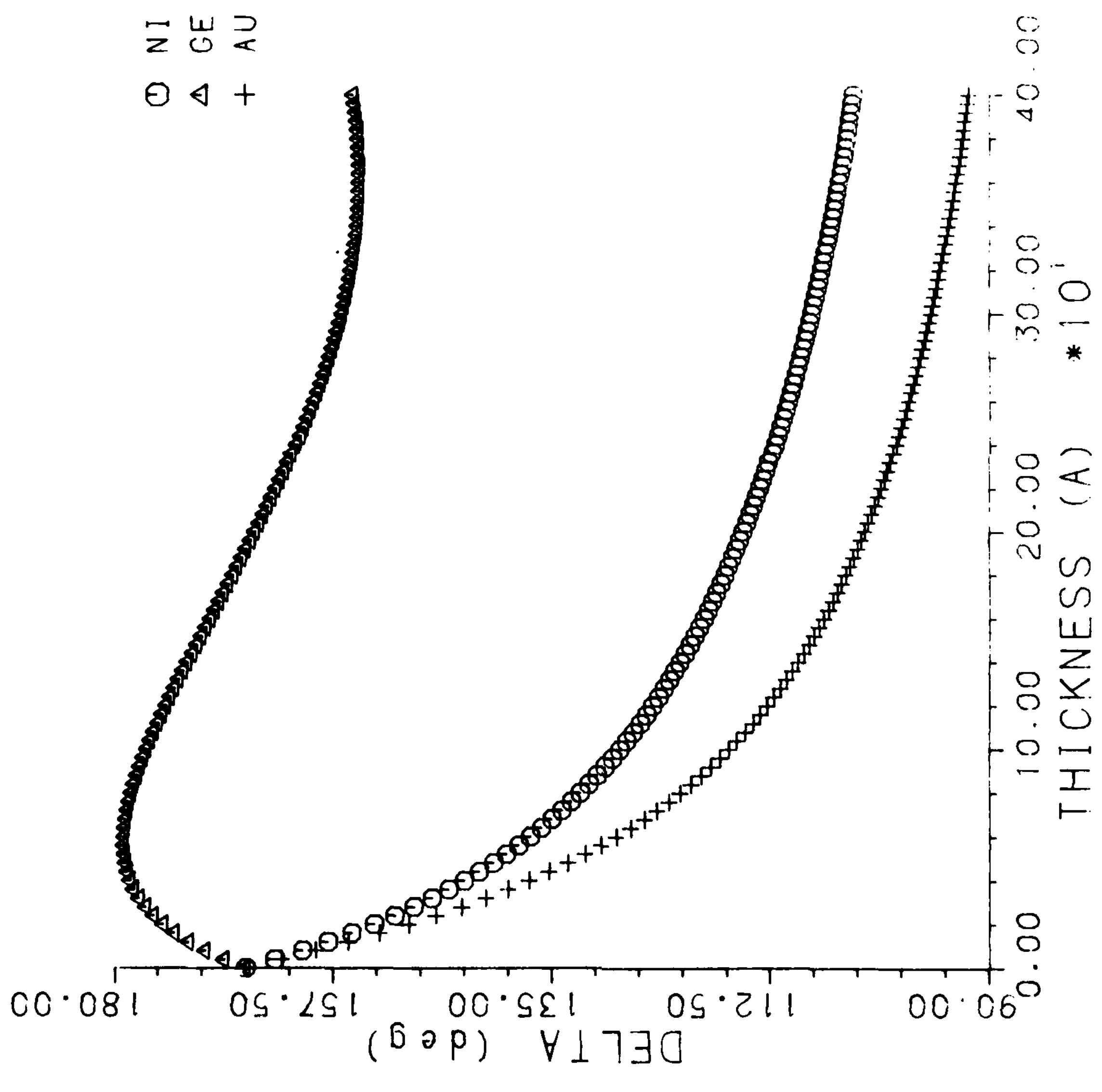

Figure 12. Computed Delta and Thickness Relationship for Metal Films Ni, Ge, and Au

SECTION V

DISCUSSION AND SUMMARY

Ellipsometric data has been obtained from a number of commercially prepared gallium arsenide wafers. The wafers were 50mm in diameter and had a polished surface. The optical constants were measured from the as-received surfaces. A grid procedure consisting of the as-received delta and psi readings and literature values for n_s and k_s^* is proposed for finding the optical constants of a film-free surface.

Using the optical constant for the film-free surface a series of experimental and computer studies were performed for dielectric, epitaxial, and metal films on gallium arsenide. When dealing with very thin dielectric films, good fits can be obtained between observed and calculated data giving a reasonable measure of film thickness. However, the optical constants for these thin films cannot be obtained with any accuracy by ellipsometry, because delta and psi approach the same values regardless of the optical constants of the film as the thickness tends towards zero.

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